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HELMET MOUNTED DISPLAY OPTICAL DESIGN.(U)

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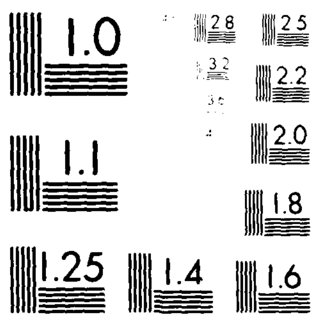
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LEVEL II

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FARRAND OPTICAL CO., INC.

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(6) HELMET MOUNTED DISPLAY
OPTICAL DESIGN

FINAL TECHNICAL REPORT

(14) ER-556

Prepared For:

U.S. Army Mobility Equipment
Research and Development Center
R&D Procurement Office
Ft. Belvoir, Va. 22030

Under Contract No.
DAAK02-71C0343

Prepared By:

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117 Wall Street
Valhalla, New York 10595

(11) Mar[redacted]74

FARRAND OPTICAL CO., INC.

FINAL TECHNICAL REPORT

FOR

HELMET MOUNTED DISPLAYS

TABLE OF CONTENTS

LIST OF TABLES

LIST OF ILLUSTRATIONS

I SUMMARY

The work performed under Phase II of this contract included the final design and fabrication of the two optical systems chosen as a result of Phase I of this program. These were:

1) Off-aperture Concave Mirror Magnifier Eyepiece — "Toroidal Mirror"; Figure 1.

2) Off-aperture Concave Mirror Eyepiece Erecting Eyepiece, ~~Figure~~ 5.

To conserve funds, both systems were manufactured with totally reflecting eyepiece mirrors eliminating the cost of the second surface at this time. For the same reason, minimum mounts only suitable for optical testing were supplied.

To permit the use of one common CRT for use with either instrument, both systems were designed to be used with a 28.3mm x 28.3mm (40mm ϕ) format to approach as close as possible the desired 40^o x 40^o apparent field of view.

This was more than enough for the Off-aperture Concave Mirror Eyepiece Erecting Eyepiece System (which could be designed to work with a significantly smaller tube) and gave the desired 40^o vertical field when used with the toroidal mirror. However, the horizontal field was limited to approximately 32^o.

In March of 1973, the work order was modified to study "limiting parameters and their interactions effecting the horizontal field of view in the toric reflector HMD approach."

The results of this study show that the desired horizontal field can only be achieved at the expense of further reduction in image quality when the system is off-aperture or off-axis in the horizontal direction.

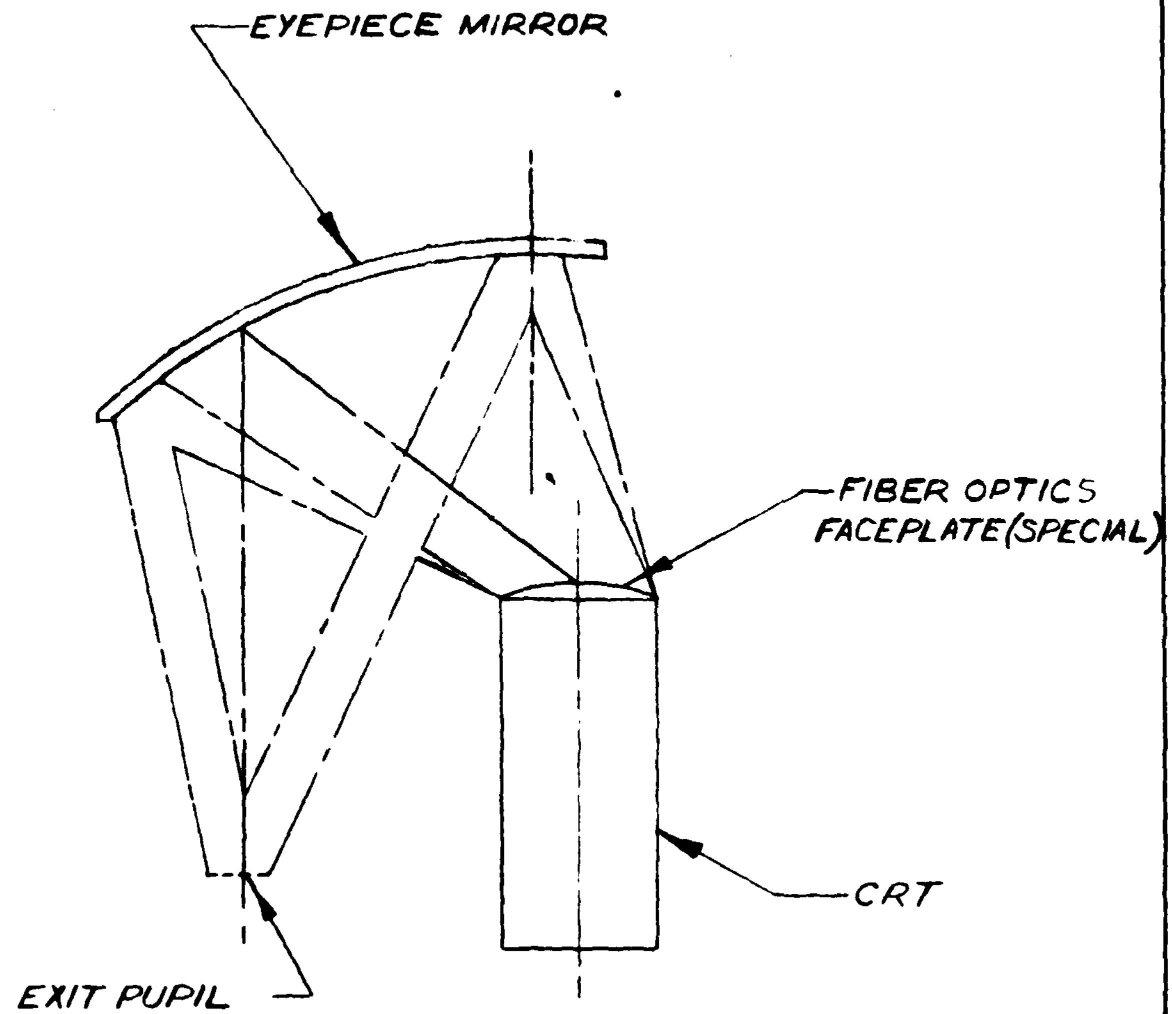


FIG. Nº 1

H.F.C. 3-29-71 — NO SCALE	DWG. Nº 138330
FARRAND OPTICAL CO., INC. BRONX BLVD. & E. 238TH ST. NEW YORK, N. Y.	OFF APERTURE CONCAVE MIRROR MAGNIFIER EYEPIECE

II CONCLUSIONS AND RECOMMENDATIONS

1) Phase I

The purpose of this phase of the program was to investigate a minimum of five (5) design approaches for a lightweight monocular Helmet Mounted Display. Each concept was to be developed to a level sufficient to allow the selection of two (2) of the approaches for design optimization, fabrication, and tests of the prototypes during Phase II.

The results of the Phase I study were reported in October, 1971, in Farrand Engineering Report #E-540. They indicated that two possible systems were worthy of being considered for final development of HMD prototypes.

They were called:

a) Off-Aperture Concave Mirror Magnifier Eyepiece

b) Off-Aperture Concave Mirror Eyepiece Erecting Eyepiece

2) Off-Aperture Concave Mirror Magnifier Eyepiece "Toric Mirror"

The use of the Toroidal mirror as the only image forming element for a Helmet Mounted Display is obviously the most desirable solution for this problem. Unfortunately, the field of view commensurate with good image performance is limited in the Off-aperture or Off-axis direction. In all of the studies this has been in the horizontal plane which is where the wide field is desired.

If a CRT were developed permitting this off-aperture fold in the vertical plane, then a horizontal field of view of 40^{o} or more could be achieved in the horizontal plane with good image quality.

3) Off-Aperture Concave Mirror Eyepiece Erecting Eyepiece

This system was eminently successful in terms of exceeding all optical requirements of the specifications utilizing 4 ounces of glass. The mount supplied with the system was strictly for optical testing and is not attachable to a normal flight helmet.

If there is interest in this system, the following steps are recommended:

a) That the system be modified to operate with a smaller tube such as one with a 20 to 25mm format.

b) That all flyable mount of this modified optical design be designed interfacing with a flight helmet. It is estimated at this time that the optics plus mount will weigh 7 ounces. It should be noted that this system may require some modification of the helmet.

III SPECIFICATIONS

1) Format and Field of View

A square with a 40mm diagonal. The 28.3 mm sides are to correspond to a 40° field of view. This means that the focal length of the system is to be approximately 39.5mm. Thus, the 40mm diagonal corresponds to a field of approximately 54°.

2) Eye Relief

The clearance from the nearest optical support or component to the vertex of the eye should be a minimum of 12mm.

3) Exit Pupil

10mm

4) Spectral Region

Corrected for P-20 phosphor as seen by the eye.

5) Weight

Less than 4 ounces

6) Focus

Should present an infinity display to observers requiring eyepiece corrections ranging from -4 to +4 diopters.

The performance specifications are as follows:

1) The MTF of the HMD should be at least 0.5 at 20 cycles/mm and at least 0.8 @ 15 cycles/mm. Corresponding to an angular resolution of 4.3 and 5.7 arc minutes respectively.

2) The residual distortion of the HMD including TV tube should be less than ±2%. The distortion and/or magnification of the outside world shall be such that no point shall deviate by more than 30 minutes.

3) Transmission

a) Display - 40%

b) Outside world - 40%

4) Stray Light

Less than 5% of the light originating in the HMD and reaching the eye shall be stray or non image forming light.

IV DESIGN APPROACHES

A) OFF-APERTURE CONCAVE MIRROR MAGNIFIER EYEPIECE

An ideal solution to the HMD optical problem is the Off-Aperture Concave Magnifier Eyepiece shown schematically in Figure 1.

Optical design analysis indicated that a reasonable solution could be achieved using a toroidal mirror.

The advantage of such a system is obvious in that there is only one active optical element, the mirror itself. In working on the design of such a system the definition of the parameters are as shown in Figure 2.

In a system that was built, these values are as follows:

RH = 88.8mm

RV = 74.3mm

$A-A^1$ = 36mm

F^1-F = 6mm lateral

F^1-F = 9.6mm longitudinal (BFL=34.8 measured along axis AV)

$\alpha = 10^o$

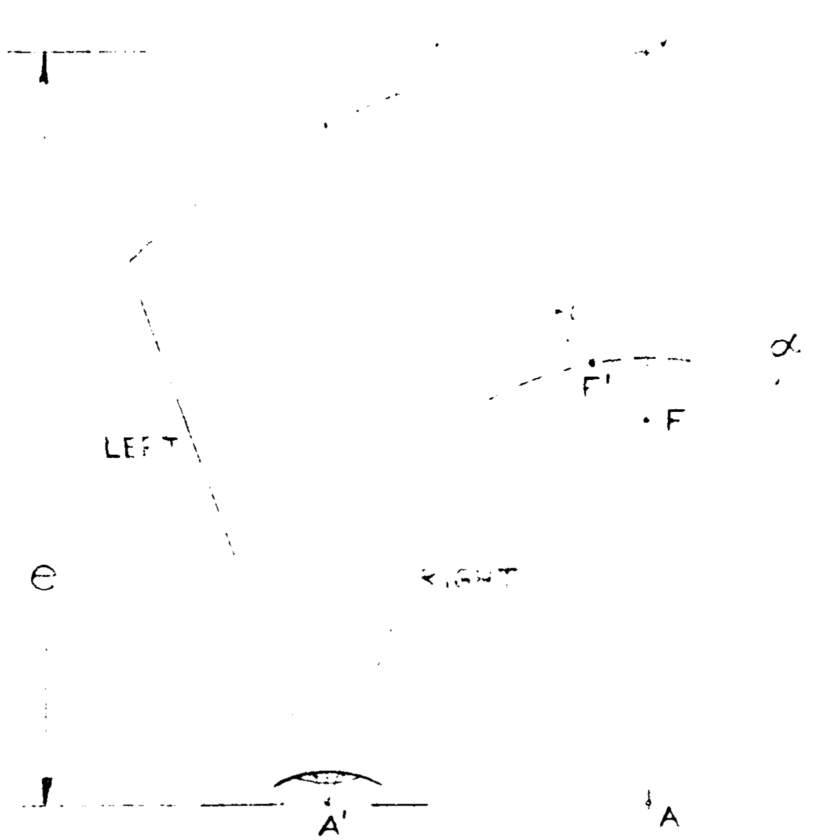
$\gamma = 47.8^o$

e = 80mm

R_i = 40mm convex

The system is shown in almost exact scale in Figures 3 and 4.

Table 1 shows the dioptral variation left and right and up in the field of view.



A - optical axis of mirror

A' - axis of center of pupil

Dist-A'-A - off aperture distance

F - paraxial image point

F' - actual axial image point (displaced laterally and longitudinally from F)

R_H - horizontal radius of curvature

R_V - vertical radius of curvature

R_I - radius of object surface

α - tilt of object surface relative to line parallel to axis A

γ - angle of off-aperture axial ray

e - eye relief measured along A' axis

FIG. 2

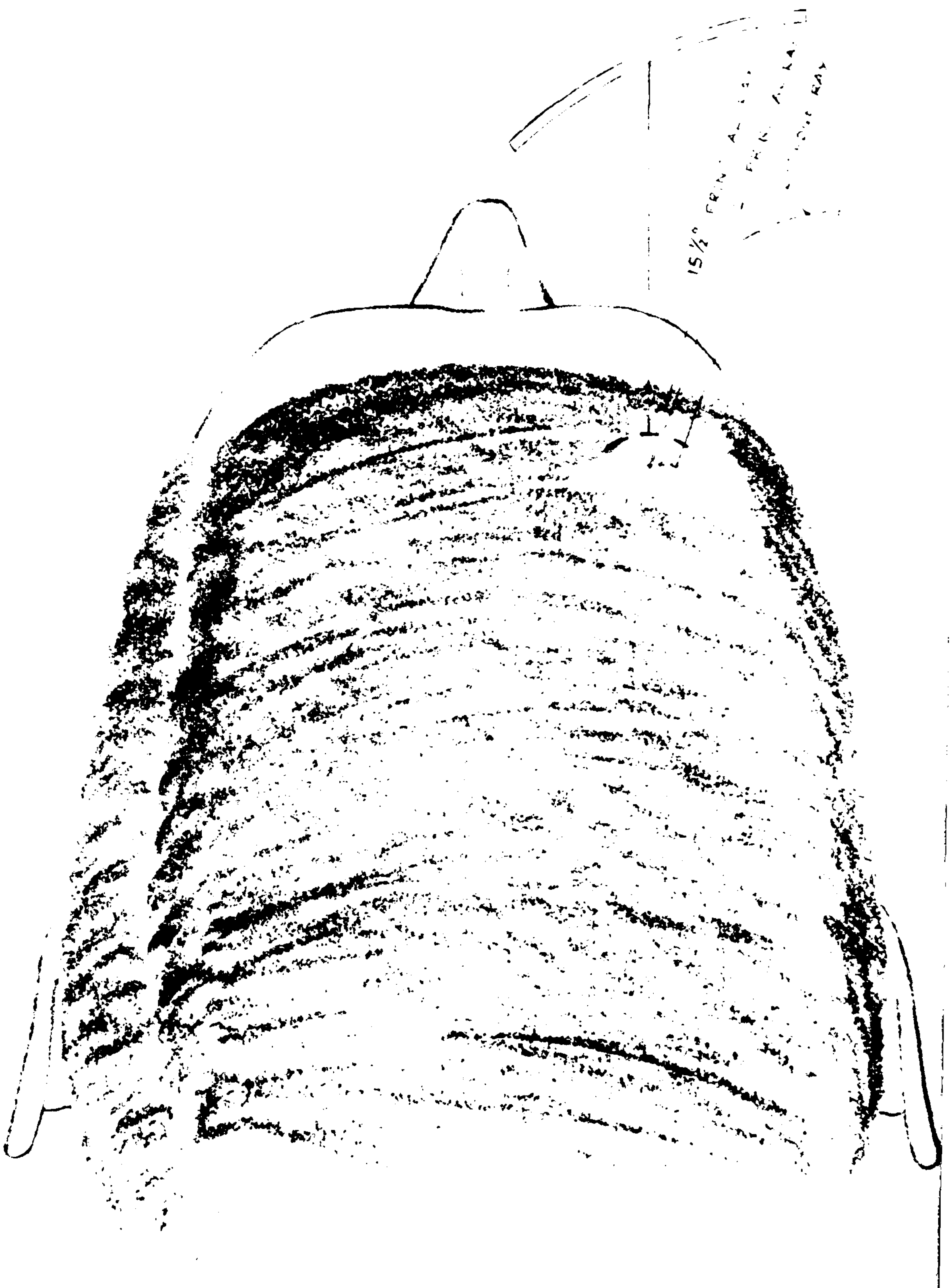
DRAWN		
APPROVED		
SCALE		

FARRAND OPTICAL CO., INC.
117 WALL ST. VALHALLA, N.Y. 10595

	SIZE	CODE IDENT NO.	DRAWING NO.
OFF APERTURE CONCAVE MIRROR MAGNIFIER EYEPIECE - OPTICAL LAYOUT	A	21587	140363

USED ON

5 4 3



3 | 2 | 1

17

D

C

B

A

FIG. 2

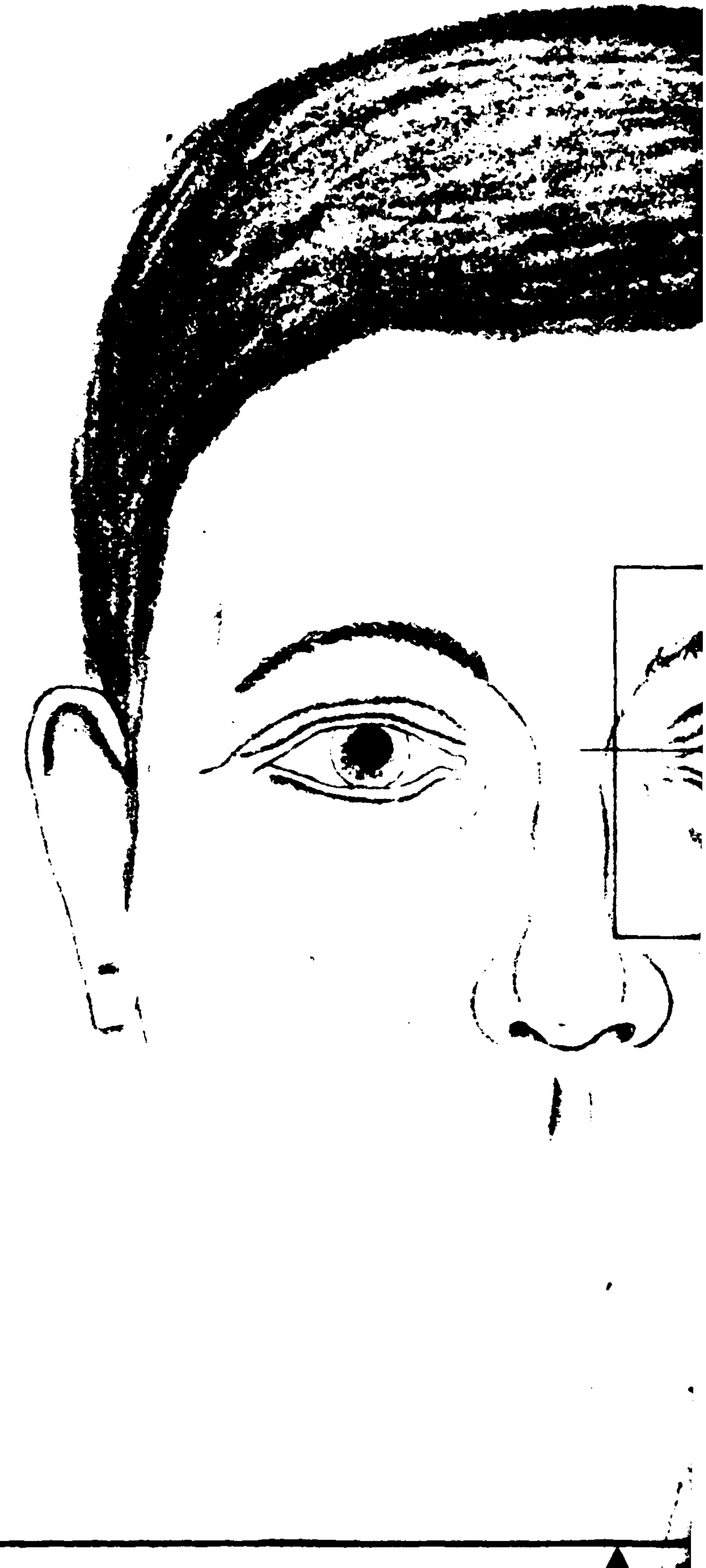
DRAWN		FARRAND OPTICAL CO., INC.	
APPROVED		117 WALL ST.	VALHALLA, N.Y. 10595
SCALE			

OFF-APERTURE CONCAVE MIRROR MAGNIFIER EYEPIECE – TOP VIEW	SIZE B	CODE IDENT NO 21587	DRAWING NO 140362

USED ON

1, 2

5 4 3



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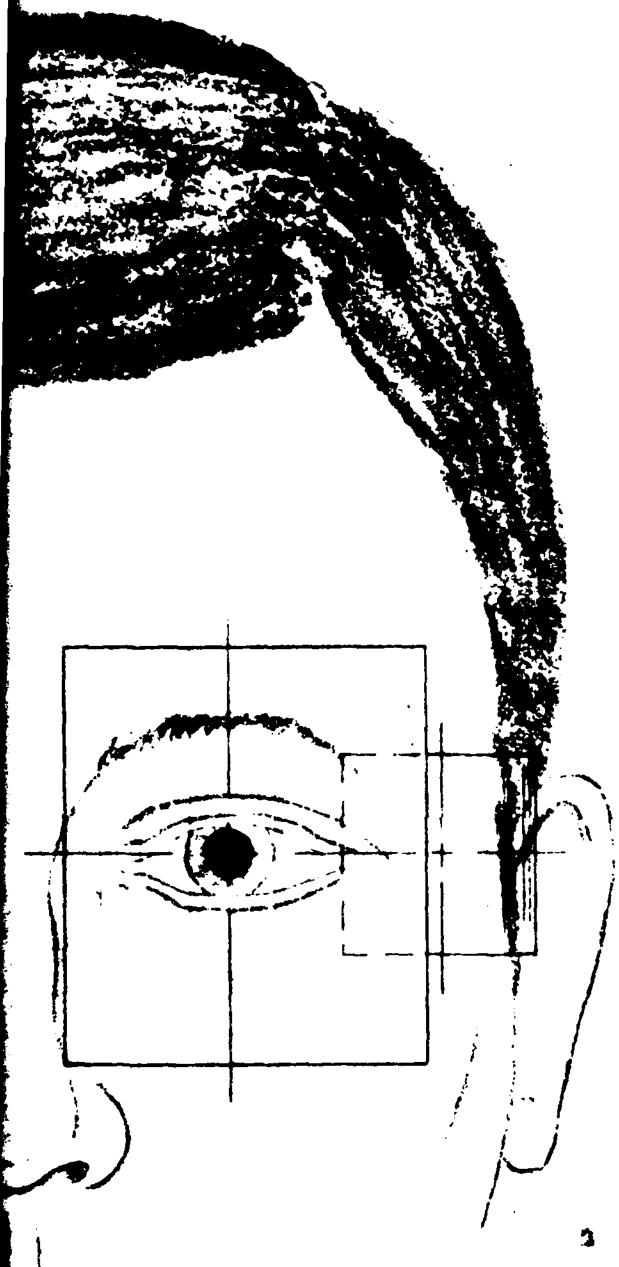

FIG. 4

DRAWN			FARRAND OPTICAL CO., INC.
APPROVED			117 WALL ST VALHALLA, N.Y. 10595
SCALE			

OFF APERTURE CONCAVE MIRROR MAGNIFIER EYEPIECE - FRONT VIEW	SIZE B	CODE IDENT NO 21587	DRAWING NO 140361

USED ON

1.2

TABLE 1 DIOPTRAL VARIATIONS - TOROIDAL MIRROR

	Hor. Pupil	Vert. Pupil
20°RT	-.3 Diopt.	0 Diopt.
10.3°RT	-.1 Diopt.	+.2 Diopt.
0°	0 Diopt.	+.1 Diopt.
10.3°LT	+.1 Diopt.	-.3 Diopt.
20°LT	+.1 Diopt.	-.7 Diopt.
20°Up	+.2 Diopt.	+.1 Diopt.
10.3°Up	+.1 Diopt.	+.1 Diopt.
10.3°RT 10.3°Up	0 Diopt.	+.3 Diopt.
20°RT 20°Up	+.2 Diopt.	-.3 Diopt.
10.3°LT 10.3°Up	0 Diopt.	-.1 Diopt.
20°LT 20°Up	+.3 Diopt.	-.6 Diopt.

The computed MTF for this off-aperture Toroidal Mirror for a 5mm pupil at best focus are given in Table 2.

TABLE 2 - COMPUTED MTF - TOROIDAL MIRROR

0°	Vert. Pupil	Hor. Pupil
Focus	.1mm	.2mm
Freq LP/mm		
5	98.1%	87.0%
10	92.5%	62.4%
15	83.9%	45.0%
20	73.0%	32.5%
25	61.0%	23.5%

TABLE 2 (CONT.)

10°RT Freq. LP/mm	Vert. Focus +.2	Hor. Focus 0	10°LT Vert. Focus +.1	Hor. Focus 0
5	96.8%	83.7%	97.5%	85.6%
10	87.7%	52.8%	90.4%	56.7%
15	74.1%	41.2%	79.6%	45.5%
20	58.1%	31.3%	66.4%	44.0%
25	42.1%	3.8%	52.4%	26.7%

20°RT

Freq. LP/mm	Vert. Foc.-.05mm	Hor. Foc.-.1mm
5	98.1%	87.1
10	92.5%	63.3%
15	83.[illegible]	47.0%
20	73.0%	34.0%
25	61.0%	24.[illegible]

20°LT

Freq. LP/mm	Vert. Foc.-.9mm	Hor. Foc.+.25mm
5	99.2%	95.9%
10	96.9%	84.[illegible]
15	93.1%	69.5%
20	88.1%	53.5%
25	82.[illegible]	39.9%

10°Up

Freq. LP/mm	Vert. Foc.+.1	Hor. Foc.+.4
5	92.7	7[illegible].0%
10	73.[illegible]	[illegible]3.1%
15	50.[illegible]	24.1%
20	31.[illegible]	15.2%
25	21.7	15.8%

20°Up

Freq. LP/mm	Vert. Foc.+.[illegible]	Hor. Foc.+.4
5	78.0%	37.9%
10	34.1%	12.9%
15	9.3%	7.5%
20	4.4%	6.6%
25	6.7%	4.0%

Thus the image quality of this very simple system is reasonable.

However, there are some negative factors that must be considered. This is in the area of the size object required to present the $40^{o} \times 40^{o}$ field to the observer. This is shown in the table of mapping data for this system listed below:

TABLE 3 - MAPPING-OFF-APERTURE TOROIDAL MIRROR

20^{o}RT	18.34mmRT
15.0^{o}RT	14.39mmRT
10.3^{o}RT	9.45mmRT
10.3^{o}LT	8.94mmLT
16.8^{o}LT	14.2mmLT
20^{o}LT	16.57mmLT
10.3^{o}Up	7.30mmUp
20^{o}Up	13.93mmUp

DIAGONAL

20.9^{o}Up	17.2^{o}RT	14.2mmRT	14.1mmUp	(20.0mm Radial)
18.1^{o}Up	18.1^{o}RT	15.4mmRT	12.1mmUp	(19.6mm Radial)
18.1^{o}Up	18.1^{o}LT	15.1mmLT	11.6mmUp	(19.0mm Radial)
19.1^{o}Up	19.1^{o}LT	15.8mmLT	12.1mmUp	(19.9mm Radial)
21.0^{o}Up	16.8^{o}RT	14.1mmLT	14.0mmUp	(19.9mm Radial)

The heights listed are the chordal heights on the 40mm radius curved surface, these heights are measured normal to the 10^{o} tilted axis.

Thus, if the horizontal dimension of the tube format is maintained at 28.3mm, the horizontal field is limited to 16.9^{o} left and 15.6^{o} right. Since the left side of the tube itself vignettes the right hand side of the field this is about the limit of this arrangement.

The horizontal field was considered unsatisfactory.

B. ADDENDUM TO STUDY

Under contract modification #P00004 dated April 30, 1973, this contractor was asked to evaluate these two toroidal mirrors designs and compare these results with the results reported herein.

These results are reported in Appendix A of this report.

The Army supplied drawings from another contractor that gave two designs of toroidal mirrors that were said to supply the desired 40^{o} horizontal field from the 28.3mm width format.

C. OFF-APERTURE MIRROR EYEPIECE ERECTING EYEPIECE

A schematic layout of this system is shown in Figure 5. Pictures of the completed system are shown in Figure 6. It differs from that shown in Figures 12 and 13 of the design study report in that it was found to be possible to eliminate the two folding prisms indicated in those layouts. In addition, the overall focal length was increased to make the system compatable with the 28.3mm width and height = 40^{o} requirement.

The dioptral variation for this system with a 42mm radius concave input surface is listed in Table 4.

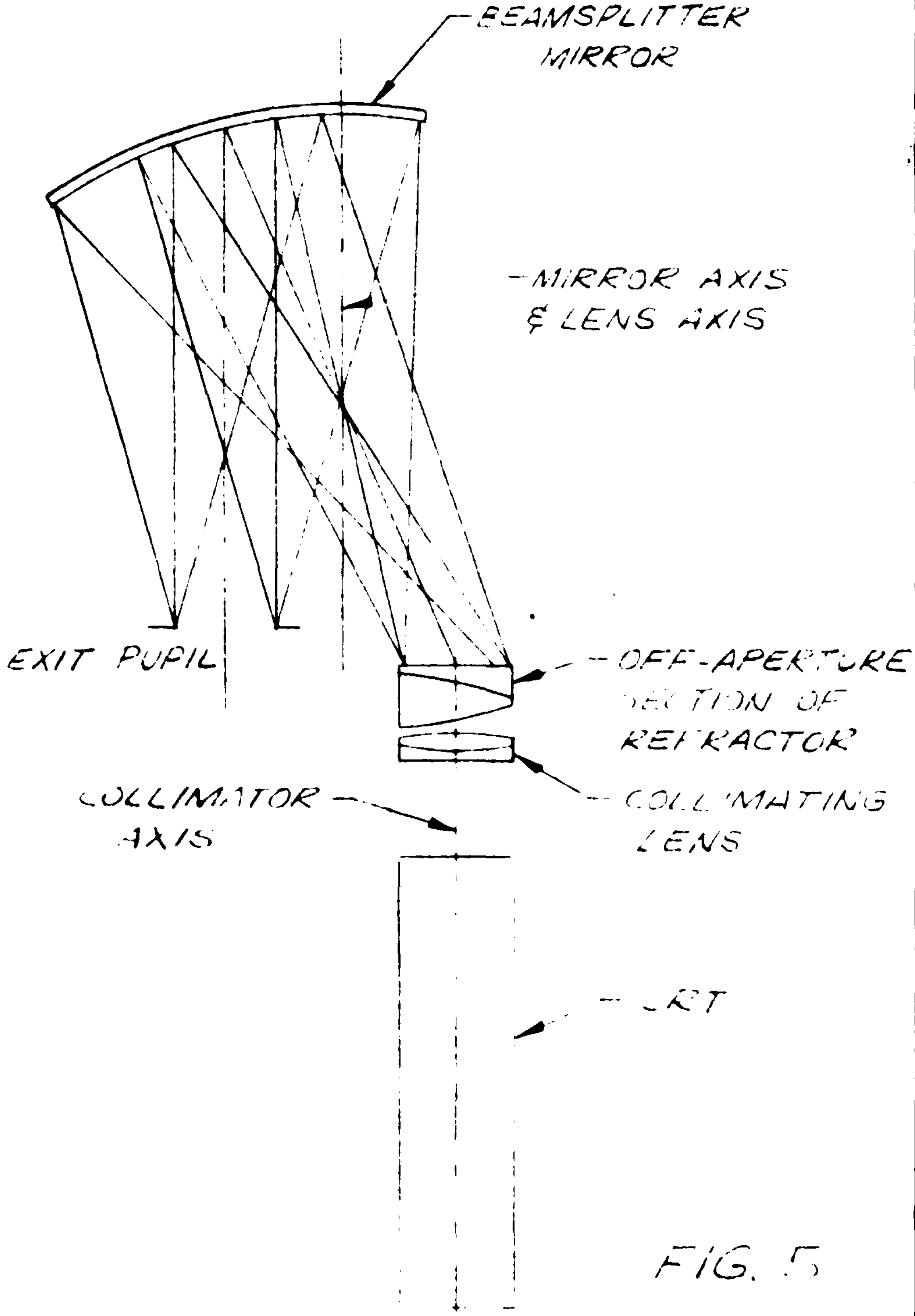

FIG. 5

DWG NO 138329

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FARRAND OPTICAL CO., INC.
BRONX BLVD. & E. 238TH ST.
NEW YORK, N. Y.

OFF APERTURE CONCAVE MIRROR EYEPIECE REFRACTING EYEPIECE

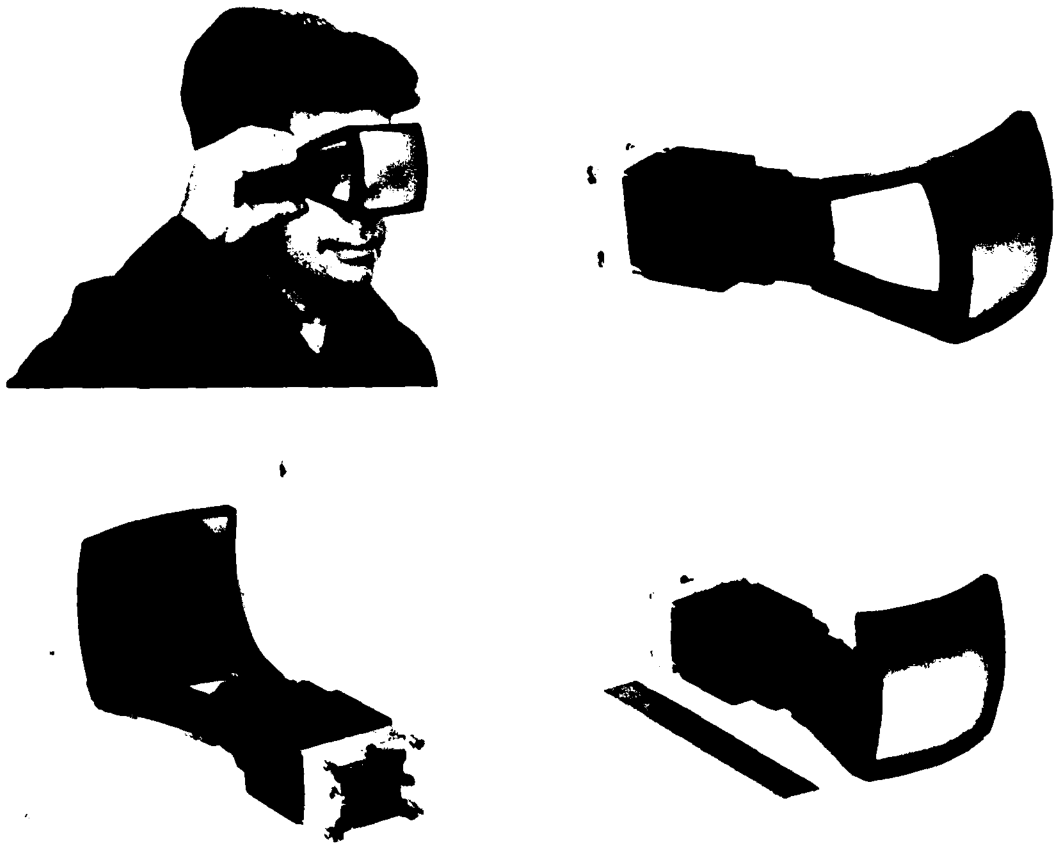


FIG. 6 - OFF-APERTURE CONCAVE MIRROR EYEPIECE
ERECTING EYEPIECE - PHOTOGRAPH

TABLE 4 - DIOPTRAL VARIATION

OFF-APERTURE CONCAVE MIRROR EYEPIECE ERECTING EYEPIECE

	Vert. Pupil	Hor. Pupil
20°RT	+.8 Diopt.	-.3 Diopt.
10.3°RT	+.7	+.3
0°	+.6	+.3
10.3°LT	+.8	+.1
20°LT	+1.4	+.3
10.3°Up	+.4	+.4
20°Up	+.4	0

The monochromatic MTF has been computed for a 5mm pupil at best focus and is shown in Table 5.

TABLE 5 - COMPUTED MTF

OFF-APERTURE MIRROR EYEPIECE ERECTING EYEPIECE

Freq. LP/mm		0^{o} Vert. Pup.	Hor. Pup.	10.3^{o}RT Vert. Pup.	Hor. Pup.	10.3^{o}LT Vert. Pup.	Hor. Pup.	10.3^{o}Up Vert. Pup.	Hor. Pup.
	Focus	+.3mm	+.4mm	+.9mm	+.3mm	+.1mm	+.1mm	+.4mm	+.5mm
5		100%	1.00	99.9	99.7	99.9	99.8	99.4	99.3
10		99.8%	99.9	99.5	98.9	99.7	99.1	97.7	97.3
15		99.6	99.8	98.8	97.5	99.4	97.9	94.9	94.1
20		99.2	99.6	97.9	95.6	98.9	96.4	91.1	89.6
25		98.8	99.3	96.7	93.2	98.3	94.4	86.4	84.9

		Vert. Pup.	Hor. Pup.	Vert. Pup.	Hor. Pup.	Vert. Pup.	Hor. Pup.
	Focus	+.9mm	-.4mm	+1.8mm	+.4mm	+.6mm	0mm
5		99.8%	99.8	99.8	99.3	99.0	98.7
10		99.3	99.1	99.2	97.4	96.1	94.7
15		98.3	98.0	98.2	94.3	91.5	88.4
20		97.0	96.5	96.8	90.0	85.3	79.9
25		95.4	94.6	95.0	84.8	78.0	69.7

The mapping for this system is shown in Table 6 below.

TABLE 6 - MAPPING

OFF-APERTURE MIRROR EYEPIECE ERECTING EYEPIECE

	Hor.	Vert.
20^{o}RT	12.60mm	
10.3^{o}RT	6.28mm	
0^{o}	0	
10.3^{o}LT	6.15mm	
20^{o}LT	11.87mm	
10.3^{o}Up	.32mm	6.54mm
20^{o}Up	1.23mm	12.84mm

DIAGONAL	Hor.	Vert.
20^{o}RT 20^{o}Up	14.03mm	12.33
10.3^{o}RT 10.3^{o}Up	6.56mm	6.25
10.3^{o}LT 10.3^{o}Up	5.77	6.76
20^{o}LT 20^{o}Up	10.63	13.71

The prototype system was delivered to Night Vision Labs on December 7, 1972. The glass element weight was four ounces. While the nominal design pupil was 10mm, overdimensioning allowed a 16mm vertical by 14mm horizontal pupil in this unit. With a ground glass Concave surface simulating the tube, a field of 43^{o} vertical by 41^{o} horizontal was measured.

APPENDIX A

The manufactured toroidal mirror shown in Figure 1 was considered satisfactory in terms of performance as computed. However, the limited 32.50 horizontal field of view was considered unsatisfactory.

The Army supplied drawings from another contractor that gave two designs of Toroidal Mirrors that could supply the desired 40^{o} horizontal field of view from the 28.3mm width of the 40mm tube.

Under contract modification #P00004 dated April 30, 1973, this contractor was asked to evaluate the two Toroidal Mirrors Designs and compare their evaluations with that reported earlier in this report.

These Toroidal mirror designs both differ from the one reported herein in that while we consider this mirror to be an off-aperture section of a mirror these two designs are axial sections of Toroidal Mirrors that are tilted relative to the observing axis.

The first is a front surface Toroidal and the second is a Mangin Toroid.

A - Front Surface Toroid, Figure 7.

R_H = 87.27mm

R_V = 73.03mm

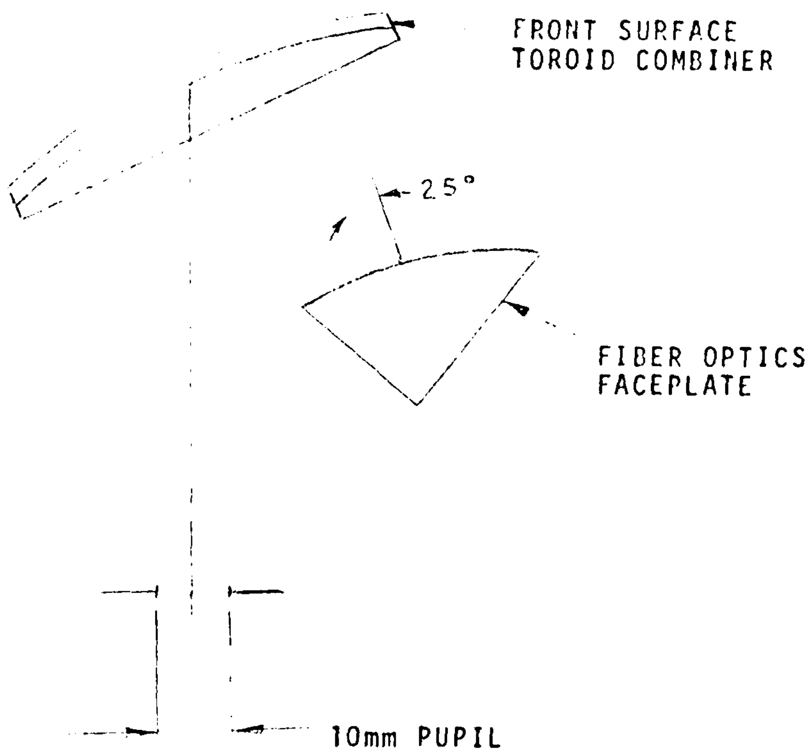


FIG. 7

143474

FARRAND OPTICAL CO., INC.
117 WALL STREET
VALHALLA, NEW YORK 10595

FRONT SURFACE TOROID

The mirror is tilted at 25^{o} to the line of sight giving a 50^{o} deviation of the line of sight as shown in Figure 7. The object surface is also toroidal with

R_H = 52.9mm

R_V = 70.8mm

The first evaluation of this system was performed with the object surface normal to this reflected line of sight.

Table 7 shows the dioptral variation of this system.

TABLE 7

Field ∡	Vert. Pupil	Hor. Pupil
20^{o}RT	-7.1 Diopt.	-3.3 Diopt.
10.3^{o}RT	-3.5 Diopt.	-1.8 Diopt.
0^{o}	+0.6 Diopt.	0
10.3^{o}LT	+5.0 Diopt.	+2.2 Diopt.
20^{o}LT	+9.4 Diopt.	+4.0 Diopt.
10.3^{o}Up	+0.5 Diopt.	0
20^{o}Up	+0.5 Diopt.	+.1 Diopt.

The mapping of this system is given in Table 8.

TABLE 8

20^{o}RT	13.77mmRT	
10.3^{o}RT	7.09mmRT	
0	0	0
10.3^{o}LT	7.21mmLT	
20^{o} LT	14.29mmLT	
10.3^{o}Up	0.55mmRT	7.27mmUp
20^{o}Up	2.05mmRT	13.89mmUp

Thus the system satisfies the field of view requirements in terms of angle versus linear field but the system is not useable in this form because of the tremendous focus variation across the field of view.

To alleviate this focus difference the input is tilted significantly at its vertex.

We have recomputed the system with this input tilted 25°.

The dioptral variation of this system is given in Table 9.

TABLE 9

	Vert. Pupil	Hor. Pupil
20°RT	-1.5 Diopt.	-0.1 Diopt.
10.3°RT	-0.6 Diopt.	0
0	+0.5 Diopt.	0
10.3°LT	+1.6 Diopt.	+0.5 Diopt.
20°LT	+3.1 Diopt.	+1.7 Diopt.
10.3°Up	+0.5 Diopt.	+0.2 Diopt.
20°Up	+0.8 Diopt.	+0.7 Diopt.

The mapping of this system is given in Table 10.

TABLE 10

	Vert. Pupil	Hor. Pupil
20^{o}RT	14.87mmRT	
10.3^{o}RT	7.78mmRT	
0	0	
10.3^{o}LT	7.89mmLT	
20^{o}LT	15.34mmLT	
10.3^{o}Up	.42mmRT	7.28mmUp
20^{o}Up	1.59mmRT	14.00mmUp

Thus, with somewhat reduced field tilt the mapping changes so that the horizontal field is reduced to approximately 38^{o}.

The computed MTF for this system is as follows:

TABLE 11

0^{o}

	Vert. Pupil	Hor. Pupil
Focus	+.6mm	0
Freq. LP/mm		
5	96.9%	89.0%
10	88.0%	62.6%
15	74.8%	38.6%
20	59.1%	32.3%
25	43.2%	27.8%

TABLE 11 (CONT.)

10°RT	Vert. Pupil	Hor. Pupil	10°LT Vert. Pupil	10°LT Hor. Pupil
Focus	-1.3mm	-0.2mm	+3.1mm	+.8mm
Freq. LP/mm				
5	98.1%	93.4%	96.5%	85.9%
10	92.7%	75.9%	86.8%	55.7%
15	84.2%	53.5%	72.3%	37.0%
20	73.3%	34.9%	55.5%	31.7%
25	61%	27.1%	39.0%	18.3%

20°RT	Vert. Pupil	Hor. Pupil	20°LT Vert. Pupil	20°LT Hor. Pupil
Focus	-2.8mm	-1.1mm	+5.8mm	+2.3mm
Freq. LP/mm				
5	99.1%	96.9%	97.2%	88.0%
10	96.5%	88.1%	89.0%	59.0%
15	92.2%	74.7%	76.7%	36.4%
20	86.5%	58.8%	61.7%	33.4%
25	79.7%	42.5%	46.1%	27.6%

TABLE 11 (CONT.)

10°Up	Vert. Pupil	Hor. Pupil	20°Up Vert. Pupil	Hor. Pupil
Focus	+.1mm	+1.6mm	+2.2mm	+.1mm
Freq. LP/mm				
5	39.9%	28.9%	7.5%	14.3%
10	17.7%	16.3%	5.2%	2.5%
15	4.0%	12.3%	6.0%	2.4%
20	5.2%	9.5%	6.8%	5.3%
25	9.3%	7.4%	2.7%	15%

B. Mangin Toroid, Figure 8.

Refracting Surface

R_H = 746.8mm

R_V = 1608.7mm

Reflecting Surface

R_H = 133.4mm

R_V = 121.8mm

Thickness = 7.1mm

Glass = Schott K-5, Nd = 1.523, V=58.5

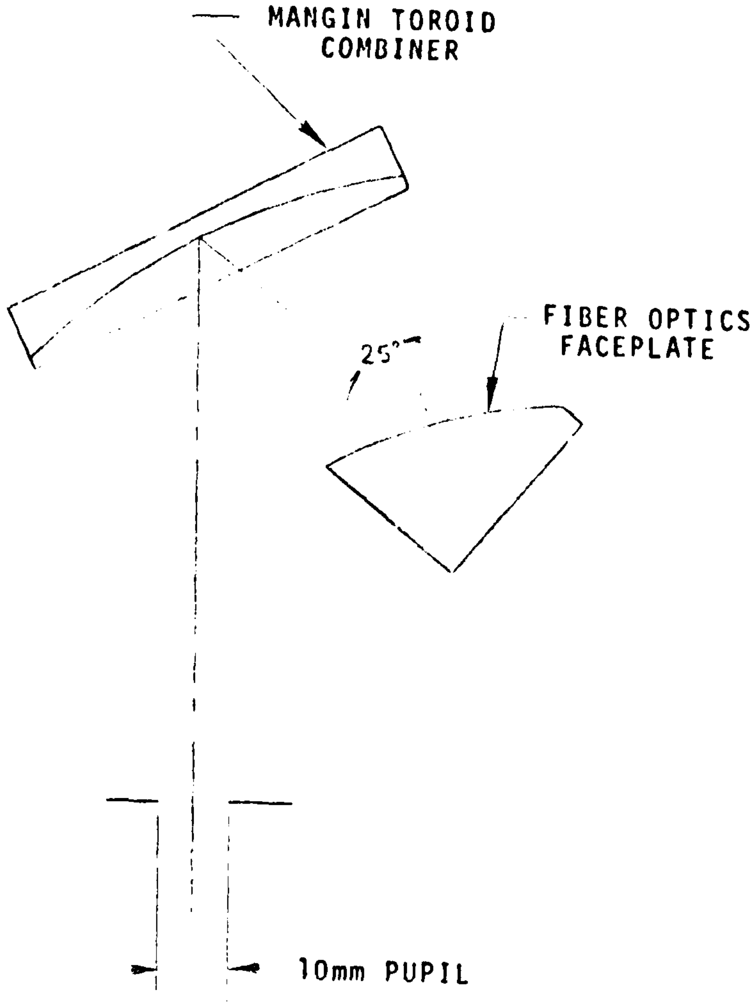
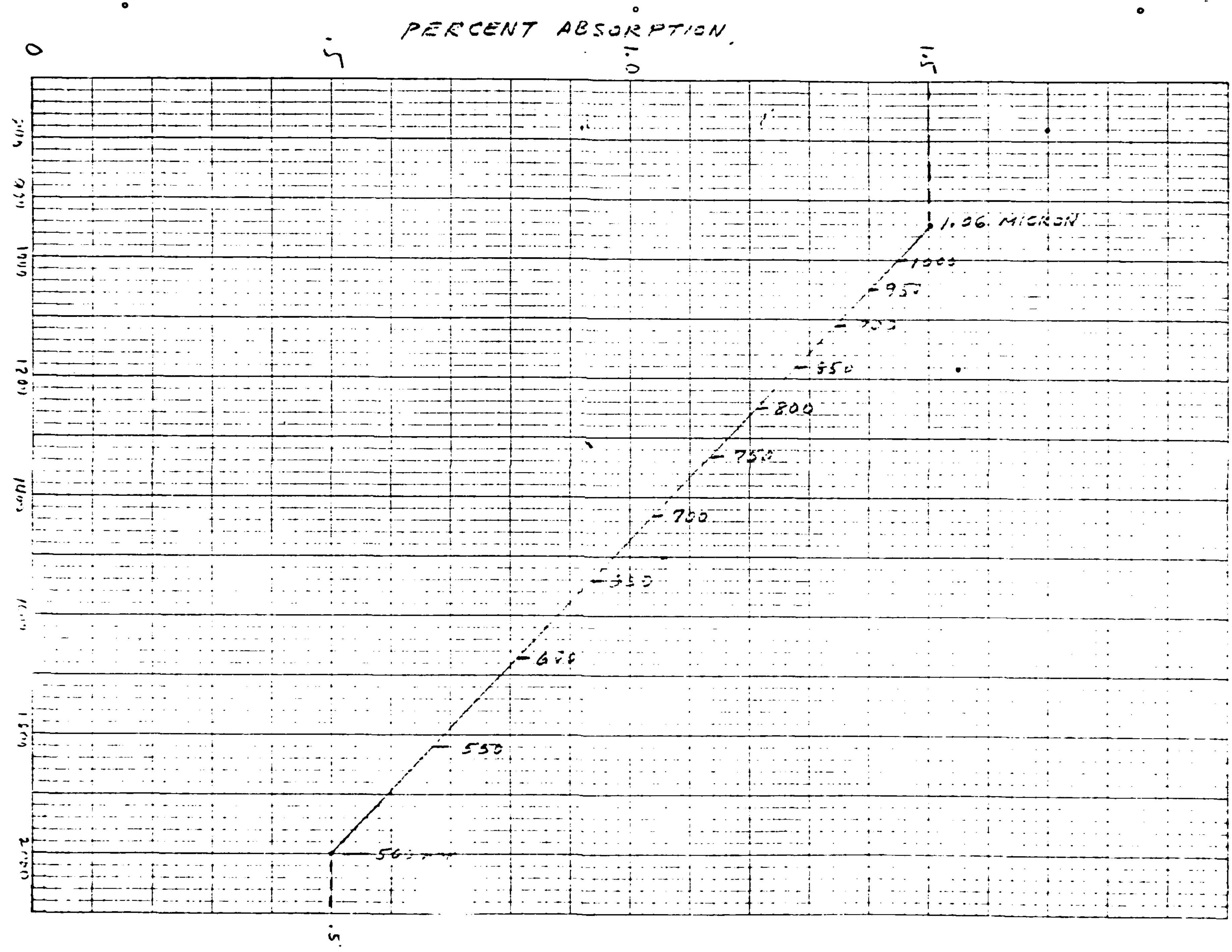


FIG. 7

143475

FARRAND OPTICAL CO., INC.
117 WALL STREET
VALHALLA, NEW YORK 10595

MANGIN TOROID SYSTEM



PERCENT ABSORPTION
0
.5
1.0
1.5
1.06 MICRON
1000
950
900
850
800
750
700
650
600
550
1200
1400
1800
2000

The mirror is tilted at 25° to the line of sight giving a 50° deviation of the line of sight as shown in Figure 8. The object surface is also toroidal with

$R_H = 52.9$mm

$R_V = 70.0$mm

The first evaluation of this system was performed with the object surface normal to this reflected line of sight.

Table 12 shows the dioptral variation of this system.

TABLE 12

Field ∠	Vert. Pupil	Hor. Pupil
20°RT	+5.0 Diopt.	+4.6 Diopt.
10.3°RT	+3.3 Diopt.	+1.8 Diopt.
0°	0.0	0
10.3°LT	-2.6 Diopt.	-3.1 Diopt.
20°LT	-5.0 Diopt.	-5.4 Diopt.
10.3°Up	+.1 Diopt.	-0.2 Diopt.
20°Up	-.6 Diopt.	-1.0 Diopt.

The mapping of this system is given in Table 13.

TABLE 13

20°RT	14.19mmRT	
10.3°RT	7.10mmRT	
0	0	0
10.3°LT	7.10mmLT	
20°LT	13.92mmLT	
10.3°Up	.3967mmRT	7.67mmUp
20°Up	1.4767mmRT	14.56mmUp

Thus the system satisfies the field of view requirements in terms of angle versus linear field but the system is not useable in this form because of the tremendous focus variation across the field of view.

To alleviate this focus difference the input is tilted significantly at its vertex.

We have recomputed the system with this input tilted 35°.

The dioptral variation of this system is given in Table 14.

TABLE 14

	Vert. Pupil	Hor. Pupil
20°RT	+0.1 Diopt.	+0.1 Diopt.
10.3°RT	+0.2 Diopt.	-0.5 Diopt.
0	0	0
10.3°LT	+0.2 Diopt.	-0.7 Diopt.
20°LT	-0.2 Diopt.	-0.7 Diopt.
10.3°Up	+0.2 Diopt.	-0.6 Diopt.
20°Up	-0.2 Diopt.	-0.5 Diopt.

The mapping of this system is given in Table 15.

TABLE 15

	Vert. Pupil	Hor. Pupil
20°RT	16.47mmRT	
17.4°RT	14.40mmRT	
10.3°RT	8.62mmRT	
0	0	
10.3°LT	8.47mmLT	
17.9°LT	14.42mmLT	
20°LT	16.01mmLT	
10.3°Up	.19mmLT	7.68mmUp
20°Up	.71mmLT	14.64mmUp

Thus, with somewhat field tilt the mapping changes so that the horizontal field is reduced to 35.3°.

The computed MTF for this system is as follows:

TABLE 16

9°

	Vert. Pupil	Hor. Pupil
Focus	+.5mm	-1.4mm
Freq. LP/mm		
5	93.2%	74.1
10	75.2%	38.6%
15	51.7%	29.5%
20	29.7%	7.7%
25	14.[illegible]	17.3%

TABLE 16 (CONT.)

	10°RT Vert. Pupil	10°RT Hor. Pupil	10°LT Vert. Pupil	10°LT Hor. Pupil
Focus	+.4mm	-.7mm	+0.3mm	-1.8mm
Freq. LP/mm				
5	94.1%	65.0%	93.8%	69.0%
10	78.1%	45.7%	77.1%	46.4%
15	56.7%	25.6%	55.1%	27.8%
20	35.4%	25.6%	34.0%	25.4%
25	19.2%	12.8%	18.7%	5.5%

	16.6°RT Vert. Pupil	16.6°RT Hor. Pupil	20°LT Vert. Pupil	20°LT Hor. Pupil
Focus	0	-0.4mm	-.3mm	-1.0mm
Freq. LP/mm				
5	96.6%	65.4%	95.3%	89.1%
10	86.8%	46.8%	82.4%	62.3%
15	72.3	27.9%	64.1%	35.0%
20	55.3	27.8%	44.3	24.8%
25	38.[illegible]%	11.1%	26.[illegible]%	21.1%

TABLE 16 (CONT.)

	10°Up		20°Up	
	Vert. Pupil	Hor. Pupil	Vert. Pupil	Hor. Pupil
Focus	+.3mm	-1.0mm	-0.39mm	-0.8mm
Freq. LP/mm				
5	93.4%	66.0%	90.9%	65.50%
10	75.9%	47.1%	68.9%	43.7%
15	53.4%	23.3%	45.0%	17.4%
20	32.5%	27.2%	31.0%	20.7%
25	18.3%	9.8%	26.3%	13.4%

DATE

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-8